SYNERGETIC APPROACH TO SOLVING THE PROBLEM OF HEARING LOSS

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Annotation. By the method of synergetic modeling, the mechanisms of development of hearing loss in humans with age have been investigated. A synergetic model for studying the auditory qualities of a person has been built and the dependence of human auditory qualities with his physiological state has been studied.

Key words: hearing loss, hearing aid, synergetics, sound, microcirculation.

Introduction. Hearing loss is a pathological condition and develops with age. In the process of aging of the human body, the state of blood vessels plays a leading role. Violation of blood microcirculation of various organs is accompanied by a change in their functional properties [1-5]. From a physical point of view, the human ear is a sound sensor equipped with a conductive channel (outer ear) and a spectrometer (inner ear) that analyzes sound signals. Currently, medical care is limited to the use of hearing aids, which amplify the power of sound signals. The quality of such devices is determined by the signal-to-noise ratio. Therefore, the task of increasing the value of this parameter arises. In addition to this technical problem, there is a physiological problem associated with the adaptation of the human body to the acoustic effects of the hearing aid. In this work, the method of synergistic modeling [6] is used to study the effect of the sound signal of the hearing aid on the blood microcirculation of the human ears.

It should be noted that the change in the functional state of the ear is one of the early benchmarks for diagnosing the aging process of the human body. If we determine the relationship between the fractal characteristics of the geometry of the blood vessels of the ear and their rheological properties with some physiological parameters of the human body, it becomes possible to develop an express method for diagnosing and monitoring the functional state of the human body [7-9], and in particular, human hearing loss.

Fractal analysis of blood microcirculation. As you know, blood microcirculation determines the physiological state of any organ. When the air temperature drops, the microcirculation of the blood of the outer ear increases, which protects it from freezing. In this way, the body ensures the preservation of the stable functioning of the organ. High-intensity sound vibrations when interacting with biological materials also affect their physiological state. The geometry of the vessels affects the state of microcirculation of the blood of human organs: the main geometric parameters of the capillary system include the length of the capillary between branches and the diameter of the capillary. These parameters change both in the norm and in the pathology of the organ. In the presence of sclerotic changes in the wall of the main vessel, it is accompanied by a change in the diameters of the capillary-d, so normally their diameter is 7 microns, and in the pathological state it increases to 16-20 microns. The volume of blood flow is determined not only by the diameter, but also by the blood flow velocity-V. Maintaining the continuity of the blood flow requires changing these parameters in accordance with the following relationship: $const=\pi\times d2\times V$.

Let us consider the dynamics of the process of changing the geometric characteristics of capillary vessels under the influence of an acoustic signal from a hearing aid.

To simplify the analysis, consider the tree-like planar structure shown in Figure 1. Let the length of the vessel between the points of b-ifurcation be equal to **a**, the opening angle between the vessels α and the linear dimensions of the coverage area of the vessels **b** and **c**

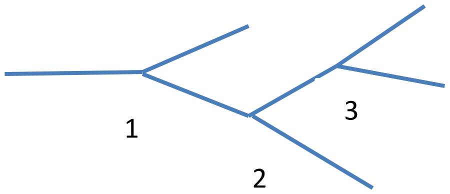

Figure 1. Dendritic structure of capillary vessels: 1,2,3 bifurcation points (bifurcation).

The longitudinal size of the bloodstream b for one bifurcation point is determined by the following relationship:

$b=2a\times\cos(\alpha/2)$;

for the nth bifurcation point $b=2n\times a\times\cos(\alpha/2)$;

Transverse dimension: $c=2a\times N\times\sin(\alpha/2)$; where N is the total number of bifurcation points depends on n according to the following relation: $N=2^n$. Using the result of simulation modeling of the development of atherosclerosis on the surface of the endothelium of a blood vessel, we obtain the following relationship: $4= (s/S)\times N$, where $s=a\times d$; $S=b\times c$. Based on the fractal analysis of the dendritic structure of the blood vessels of a human organ, a new method for modeling human hearing loss has been developed. The method was applied to study the process of blood flow in the human ear. It is shown that under conditions of homeostasis, the size distribution of blood vessels is described by the Poisson function, which is characterized by the equality of the average value of the size with its dispersion. At the critical point of the transition from normal to pathological, an abnormal dispersion of the physiological parameters of the human ears is observed. Therefore, under equilibrium conditions, the possibility of a structural phase transition of the dense structure => loose structure type arises. The fractal dimension of blood vessels determines some features of phase transitions and is calculated by the formula:

$$\gamma = \ln(n)/\ln(R/r). \quad (1)$$

The dependence between the density of the circulatory network of the blood flow on its size was studied (Fig. 2):

$$\ln(\rho) = \ln(const) - d\ \ln(R) \quad (2)$$

As can be seen from this figure, there is an interval [Rmin-Rmax] of sizes within which the network of capillaries has a fractal structure.

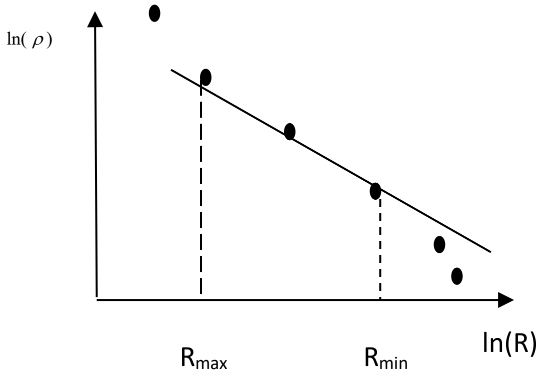

Fig.2. The dependence of the density of the network of blood vessels on their size

The main properties of the capillary network of a human organ, depending on the fractality of its structure, are reduced to the following provisions:

a) the density of blood vessels decreases with an increase in its size - R;

b) with an increase in the fractal dimension of a macromolecule, the slope of the dependence of density on size decreases

c) The fractality of the macromolecule structure is limited on both sides in size, and the lower - Rmin and upper - Rmax limits are determined by comparison with experimental data (semi-empirical approach).

Synergetic modeling of microcirculation processes carried out by implementing the following two stages,

a) determining the density of blood vessels on the surface of the organ;

b) selection of a slowly changing physiological characteristic of an organ as an order parameter.

Fractal representations of the geometry of blood vessels make it possible to find a control parameter and establish a relationship between the control parameter and the physical characteristics of external influences (for example, the effect of a hearing aid on the physiological and functional state of the human auditory system).

Fractal structure of blood vessels and issues of human hearing loss.

In the process of measuring a physical quantity, a numerical value is determined by comparison with a certain measure. The choice of the unit of measurement is arbitrary. If the length of the line is compared with the meter standard, then the surface area and volume of the figure have the dimensions of a square meter and a cube meter, respectively. However, it is possible to construct such figures, the dimension of which may turn out to be fractional (fractal). Let's build the following figure from 4 segments equal to one meter. The numerical value of the distances between the ends in a straight line R=3; along the contour of the broken line L=4 (Fig. 3a). Reduce the scale of the figure 3 times and increase their number to four. From them we will build the original figure again (Fig. 3b).

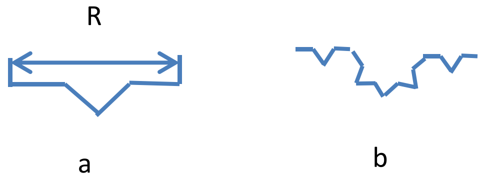

Fig.3. Koch figures.

Repeating this procedure N times, we obtain the so-called Koch figures. Its dimension is determined by the formula:

$$n=\frac{\ln(\frac{L}{a})}{\ln(\frac{R}{a})}=\frac{\ln 4}{\ln 3}=1.26 \quad (3)$$

A distinctive feature of fractal structures is their fractional dimension and self-similarity property. Such geometric objects become models in the study of a number of synergetic phenomena. The integer part determines the number of order parameters, and the fractional part determines random features in the behavior of the object under study. The methods of fractal geometry in combination with the concepts of synergetic make it possible to model the behavior of nonlinear systems under highly nonequilibrium conditions.

The degree of conjugation of acoustic and physiological effects depends on a number of parameters (stress, relative deformation of the tympanic membrane and technical characteristics of the hearing aid). More generally, the acoustic-physiological conjugation is associated with the fractal parameters of the microcirculatory network of blood vessels and is determined by the geometry of the blood vessels of a human organ. We have previously studied thermomechanical conjugation in organic glasses using the result of Kosevich showing that the root-mean-square displacement of atoms from the equilibrium position becomes proportional to the crystal parameters: $<u^2> \approx \ln (L/a)$ (4) [10], here L is the size of a linear defect in a two-dimensional crystal (dislocation), a is the lattice constant of the crystal. In this paper, formula (4) for the root-mean-square displacement of atoms is interpreted using the following functional dependence: $<u^2>= f(u, n)$, (5) where n is the fractal dimension of the blood microcirculation system in human ear capillaries, u - control parameter, depending on the following characteristics of the hearing aid: sound power, spectral characteristic of the apparatus noise. Determining the explicit type of functional dependence (5) is of great practical importance in the development of hearing aids and medical diagnostics.

In practical terms, it opens up the possibility of monitoring the physiological state of a person and creating comfortable conditions for a person with hearing loss.

Conclusion. A new approach to improve the hearing aid and control the physiological state of a person based on the analysis of the geometry of blood vessels is proposed. A relationship has been found between microcirculation parameters and acoustic effects on the human hearing system. It is shown that to measure the acoustic and physiological parameters of the human hearing system, a new synergistic approach to their study is required based on the representations of fractal geometry.

Based on the methods of fractal geometry, the processes of blood microcirculation in human organs have been studied;

The mechanism of influence of the technical characteristics of the hearing aid on the physiological state of the human hearing system was determined;

The geometric characteristics of blood vessels were used to determine the fractal dimension of the human hearing system;

A synergistic modeling of the process of acoustic-physiological conjugation in the conditions of the development of hearing loss in humans was carried out.

Summing up, we note that fractal geometry in combination with synergistic ideas about the functioning of human organs provide new opportunities for improving the technical means of service and control in medicine. Further development of research along this path brings us closer to understanding the deep patterns of human interaction with intellectual technical means of assisting and supporting human health.

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